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ENERGETIC ELECTRONS OF TERRESTRIAL ORIGIN BEHIND THE BOW SHOCK AND UPSTREAM IN THE SOLAR WIND*

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ABSTRACT

Energetic electron fluxes associated with the earth's bow shock are found to be present about as often on the dawn side of the sun-earth line as on the dusk side. The peak fluxes in these spikes also show no dawn-dusk asymmetry. Upstream electron events on the other hand are predominantly found to the dawn side of the sun-earth line. Both phenomena have the same temporal character with characteristic times of 30 to 150 seconds. Both have characteristic energies of about 15 KeV but the upstream electron fluxes are much weaker. The upstream events are interpreted to be of secondary origin with the bow shock spikes representing the primary acceleration event. This local acceleration process evidently is of no consequence to the problem of the Van Allen belts and auroral processes.

INTRODUCTION

Fan et al. (1964) first attributed the existence of the energetic electron spikes detached from the trapped radiation on the sunward side of the earth to an effect of the bow shock. A few months later Frank and Van Allen (1964) described additional examples of this phenomenon and noted their existence throughout much of the magnetosheath region. They hypothesized that these energetic particles were the spectral tail of the hot electron component of the magnetosheath plasma.

Further observational studies of this phenomenon were reported by Anderson, Harris and Paoli (1965) and by Anderson (1965). This work confirmed the earlier studies but a still different hypothesis for the origin of these particles was given. They thought that trapped radiation could be sloughed off and then travel along field lines through the magnetosheath. All these early studies left unanswered the question of spatial distribution of the spikes and their precise relationship to the bow shock. In 1966 both Anderson and Fan et al. presented evidence showing that the spikes could not originate as sloughed-off Van Allen radiation. In these 1966 studies a relationship to the bow shock was demonstrated but the precise location of the spikes with respect to the shock was not determined. Also in 1966, Lin and Anderson found that in a few cases the bow shock spikes had the same quasi-periodic character as trapped electrons especially in the skirt region. The observational picture was greatly clarified following Binsack's (1966) observation that bow shock spikes appeared in greatest number and in largest intensity when the magnetopause was in rapid, large amplitude motion. Anderson, Binsack and Fairfield (1968) then showed the magnetopause motion was present most of the time, the spatial amplitude varied from 0.2 to 2 R_e and that the motion was periodic or quasi-periodic with peak spacings of 3 to 15 minutes. Furthermore, it was shown that the bow shock moved with about the same period and spatial amplitude as did the magnetopause and they concluded that the magnetopause motion must be coherent over distance ≥ 10 R_e. The nature of the large, coherent oscillations of the magnetopause is not known but they may be surface waves generated by an instability of the Kelvin-Helmholtz type. An important consequence of coherent magnetopause motion is that it will drive the shock in and out with the same period and amplitude. Since the magnetosphere as a whole is a good hydromagnetic medium the surface oscillations result in the propagation of h-m waves throughout much of the magnetosphere. Such waves result in a periodic modulation of trapped energetic electron fluxes as shown by Judge and Coleman (1962) and by Lin and Anderson (1966). The energetic electron spikes were shown to be located in the magnetosheath just behind the shock. The origin of the energetic electron spikes was ascribed to dissipation of energy in the hydromagnetic waves which populate the magnetosheath.

One more phenomenon may be fitted into this picture. Anderson, Harris and Paoli (1965), Jokipii (1968) and Anderson (1968) have shown that energetic electron spikes often appear far outside even the most distant excursion of the bow shock. These particles most likely originate as spikes just behind the bow shock, then are guided to their upstream point of observation by field lines passing through the bow shock into interplanetary space. Some no doubt move in the other direction and account for some of the transient fluxes observed in the magnetosheath (see Figure 1).

The mechanism by which the electrons are accelerated behind the bow shock is not well known. Jokipii (1968) has recently made a detailed correlation study with on-board magnetometer records. He could find no magnetic structures specifically associated with the electron spikes making it unlikely that acceleration was occurring in a first-order Fermi process as suggested by Jokipii and Davis (1964). He did find some evidence that when upstream events occurred the interplanetary field was aligned more or less parallel to the sun-earth line and that waves with periods on the order of 30 seconds may have been present.

The purpose of the present article is to present observational data which bears on the question of the energetic electron spikes behind the bow shock. In particular, we show their spatial distribution between the dusk and dawn meridians on the sunward side of the earth and corresponding distributions for upstream spikes.

Figure 1 shows how the bow shock spikes are detached from the trapped particles and their general relationship to the position of the shock as determined by a magnetometer. The flux values may be noted from this Figure. Figure 2 gives a summary of the relationships discussed by Anderson, Binsack and Fairfield (1968) and briefly outlined here.

METHOD

The observations of energetic electrons used in this study come from IMP-3 and Explorer-35. The IMP-3 detector arrangement is similar in all respects to that used on IMP-2. Details may be found in Anderson, Binsack and Fairfield (1968). It should be pointed out that the IMP-2 and -3 arrangements contain two geiger-mueller tubes both having energy threshold about 40 KeV for electrons. The scatter counter has a directional response only to electrons. Its geometric factor is 2.2×10^{-3} cm^2-ster. The other counter looks directly into space with a geometric factor of 4.3×10^{-2} cm^2-ster.

The Explorer-35 detectors differ considerably from the IMP-3 detectors:

1. The scatter counter has the much larger geometric factor of 0.036 cm^2-ster. Its detection threshold is 45 KeV.
2. The open counter has an ultra-thin mica window which permits 90% of incident 22 KeV electrons to enter the sensitive volume of the counter and be detected. The geometric factor of this detector is 0.29 cm^2-ster. This device is roughly 100 times as sensitive as the scatter counter. About a factor of 10 of this is due to the geometric factor and the other factor of 10 comes from the fact that the energy spectrum of the events studied rises steeply from 45 to 22 KeV. It should be pointed out that the extreme sensitivity of this device reveals clearly many effects that cannot be seen at all in the traditional 213-type geiger-mueller tube used extensively in the past, particularly by the University of Iowa and California groups. The Explorer-35 geiger tube arrangement is shown in Figure 3.

RESULTS

The line of apsides of the IMP-3 remained nearly inertially fixed during its lifetime of almost two years. This meant it nearly completed two scans through all local times. The bow shock spikes can therefore be studied as a function of local time from near the dusk meridian through noon to the dawn meridian. No data have been analyzed behind the dusk and dawn meridians. This is because only a few degrees back the spacecraft no longer reaches the extreme outward excursions of the bow shock. The result of this study is shown in Figure 4. It is seen that bow shock spikes occur on nearly all orbits at all local times examined. Figure 5 shows detailed plots of the bow shock spikes taken near dusk, noon and dawn. They are seen to be quite similar in character. A more detailed investigation has shown that the examples are representative and in fact no strong asymmetries in intensity or temporal character exist through this region.

Further evidence that bow shock spikes exhibit no dawn-dusk asymmetry can be obtained from Explorer-35. This is a lunar-anchored spacecraft so to a good approximation it may be thought to move about the earth in a circular path of 60 R_e radius within a few degrees of the solar-ecliptic plane. Figures 6a and 6b show the locations of bow shock spikes measured in September and October of 1967. There is some evidence to be found in the bow shock spike locations for aberration of the magnetospheric tail due to the earth's orbital motion of 30 km/sec since in both cases the spikes on the dusk side are found to be somewhat closer to the sun-earth line than are the spikes on the dawn side.

Figure 7 shows detailed plots of these bow shock spikes. Again their absolute flux and general appearance is the same on the dusk side as on the dawn side of the earth.

The relation of upstream electron events to the bow shock spikes has been summarized in the Introduction to this article.

The Explorer-35 spacecraft provides an excellent way of obtaining the spatial distribution of upstream electron events since the orbit of this spacecraft lies far outside even the most distant outward excursions of the shock from dawn through noon to the dusk meridian. Examples of upstream electron events are given in Figures 8, 9 and 10. All such events encountered during two revolutions of Explorer-35 around the earth have been plotted on X_{SE}-Y_{SE} coordinates in Figure 6. This Figure shows that the upstream electron events occur predominantly on the dawn side of the sun-earth line.

A way to further check that the upstream events consist of electrons which originated as bow shock spikes and then moved away from the earth on interplanetary field lines is to measure and compare their average energy spectra. This can be done in the present experiment in only a limited way. The ratio of the excess counts in the two counters, one with a threshold of 22 KeV and the other 45 KeV, provides some spectral information. This ratio has been obtained in 15 bow shock spikes and 9 upstream spikes. The average ratio of flux > 22 KeV to the flux > 45 KeV is 4.4 ± 0.5 for bow shock spikes and 3.6 ± 0.5 for upstream spikes. The rather small difference between these two ratios can be attributed to statistical error. We conclude there is no large spectral difference between bow shock and upstream spikes. These results are summarized in Table 1 where the spectral information is expressed in terms of power law exponent, γ, and e-folding energy, E_o. The characteristic energy for these events is seen to be about 15 KeV.

Although Explorer-35 is a spinning spacecraft the present experiment in most cases cannot determine anisotropies in the energetic electron flux. This is due to the accumulation times being longer than a spin period. Such a measurement would provide a crucial test of the hypothesis favored here that the upstream particles have run upstream from behind the bow shock. If the particle fluxes should turn out to be isotropic the hypothesis (Anderson, 1968) that fast-mode waves propagating upstream from the shock couple to the solar wind to accelerate particles would be favored.

DISCUSSION

A remarkable feature of the bow shock spikes is that they have large intensity just behind the bow shock and rapidly decreasing intensity moving either toward or away from the magnetosphere (see Figure 1). The duration of a spike is 10-100 sec. In this time an electron of ~ 30 KeV energy can move from 10^6 to 10^7 Km. But Figure 1 shows that they appear only near the shock in a spatial region having dimensions of 100 to 1000 Km. This distance is arrived at by multiplying the duration of a spike by the speed of the shock motion. Heppner *et al.* (1967) find this speed to be typically 10 Km/sec. This close confinement means that a relatively small total number of energetic particles can produce an appreciable flux without excessive demands on the source strength which presumably acts only in a small region behind the shock. This idea was used by Jokipii and Davis (1964) in their theoretical analysis of the bow shock spikes. They suggested that a confinement was taking place between the shock and a magnetic field irregularity in interplanetary space. Here it is concluded that a confinement must indeed be taking place but it occurs behind the shock. Just what the magnetic field configuration is that produces a mirror geometry is less clear. One mirror surface may be the fronts of waves propagating in the magnetosheath, the other the shock itself. Heppner, *et al.* (1967) have shown that at the shock the field strength rises by several gammas above the average magnetosheath field.

Evidently the only way to avoid the conclusion that the particles are confined is to postulate a reversible effect by which particles are accelerated behind the shock but when they leave this region they become decelerated. As Jokipii and Davis have pointed out, it is more likely that a stochastic or dissipative process is at work and these cannot be reversed to decelerate the electrons.

On the model of confinement behind the shock the weaker spikes deep in the magnetosheath (see Figure 1) and the upstream spikes can be understood as a consequence of the confinement not being perfect with the result that particles gyrate along the lines of force away from the confinement region. This view is supported by the fact that while the bow shock spikes themselves show no strong asymmetry across the sun-earth line in the ecliptic plane, the upstream spikes do. They have a strong tendency to appear on the dawn side as expected from the average spiral character of the interplanetary magnetic field (see Figure 6).

The size of the confinement regions behind the shock is difficult to estimate. To do this, the motion of the region, if any, must be known. This kind of measurement could in principle, be made with two space-craft. Lacking this, extreme limits can be placed on the size: Figures 11, 12 and 13 give detailed views of some bow shock spikes. Their duration is from 30 to 150 seconds. If the duration of the spikes is determined by the spacecraft motion (confinement region stationary), the size would be 100 to 300 Km. On the other hand, when the shock is moving to and fro with speeds of about 10 Km/sec (Heppner _et al._, 1967) the size could be as large as 300 to 1500 Km.

The character of the upstream events show that theconfinement is transient. The duration of upstream events is typically 30 to 150 seconds, about the same as the parent bow shock spikes. During this time they apparently are being supplied by leakage from the confinement region. The duration does not correspond to the time required to empty the tube since the time required for electrons of these energies to move from one end of the tube to the other is only ~ 0.1 second for the largest estimate of 1500 Km.

Several stretches of observations on the bow shock spikes are long enough for the type of power spectrum analysis applied by Lin and Anderson (1966) to h-m wave modulations of energetic particles. When this analysis was performed on the bow shock spikes, significant spectral peaks were found. They ranged from 2 to 6 minutes but a great deal of spectral power was also spread over longer periods. This spectral structure is illustrated by Figure 13. The spikes are seen to be clustered with the inter-peak spacing typically a few minutes and the spacing of the clusters about 30 minutes.

The situation concerning bow shock spikes now appears to be that they represent an interesting case of particle acceleration by solar wind interaction with the earth's magnetosphere. However, if the interpretations given here are correct this particle acceleration plays no important geophysical role in the sense that the particles do not supply the Van Allen population nor do they contribute to auroral processes. Thus their further study will likely be of most interest to plasma physics.

REFERENCES

Anderson, K.A., Energetic electron fluxes in the tail of the geomagnetic field, J. Geophys. Res., 70, 4741, 1965

Anderson, K.A., Energetic electron spikes in and beyond the transition region, Proc. of the IX Int. Conf. on Cosmic Rays, London, 520, 1966

Anderson, K.A., Energetic electrons of terrestrial origin upstream in the solar wind, J. Geophys. Res., 73, 2387, 1968

Anderson, K.A., J.H. Binsack and D.H. Fairfield, Hydromagnetic disturbances of 3 to 15 minute period on the magnetopause and their relation to bow shock spikes, J. Geophys. Res., 73, 2371, 1968

Anderson, K.A., H.K. Harris and R.J. Paoli, Energetic electrons in and beyond the earth's outer magnetosphere, J. Geophys. Res., 70, 1039, 1965

Binsack, J.H., Plasma studies with the IMP-3 satellite, Ph.D. Thesis, Massachusetts Institute of Technology, 1966

Fan, C.Y., G. Gloeckler and J.A. Simpson, Evidence for > 30 KeV electrons accelerated in the shock transition region beyond the earth's magnetospheric boundary, Phys. Rev. Letters, 13, 149, 1964

Fan, C.Y., G. Gloeckler and J.A. Simpson, Acceleration of electrons near the earth's bow shock and beyond, J. Geophys. Res., 71, 1837, 1966

Frank, L.A. and J.A. Van Allen, Measurements of energetic electrons in the vicinity of the sunward magnetospheric boundary with Explorer 14, J. Geophys. Res., 69, 4923, 1964

Heppner, J.P., M. Sugiura, T.L. Skillman, B.G. Ledley and M. Campbell, OGO-A magnetic field observations, J. Geophys. Res., 72, 5417, 1967

Jokipii, J.R., Correlation of ≥ 30 KeV electron pulses and magnetic fields in the magnetosheath and beyond, J. Geophys. Res., 73, 931, 1968

Jokipii, J.R. and Leverett Davis Jr., Acceleration of electrons near the earth's bow shock, Phys. Rev. Letters, 13, 739, 1964

Judge, D.L. and P.J. Coleman, Jr., Observations of low-frequency hydromagnetic waves in the distant geomagnetic field: Explorer 6, J. Geophys. Res., 67, 5071, 1962

Lin, R.P. and K.A. Anderson, Periodic modulations of the energetic electron fluxes in the distant radiation zone, J. Geophys. Res., 71, 1827, 1966

Table 1

	Ratio of Flux > 22 KeV to Flux > 45 KeV	Integral Power Law Exponent, γ	e-folding Energy, E_o
Bow shock spikes	4.4 ± 0.5	2.1 ± 0.2	14 ± 1 KeV
Upstream spikes	3.6 ± 0.5	1.8 ± 0.2	16 ± 1 KeV

FIGURE CAPTIONS

Figure 1: Examples of bow shock spikes from IMP-2. They occur mainly from 12.5 and 13.+ R_e outbound and 14.2 to 12.8 R_e inbound. They are seen to lie near the position of the bow shock as determined by the onboard magnetometer. Note that the structures inside 11.0 R_e are not bow shock spikes. They are due to large amplitude motion of the magnetopause sweeping back and forth over the spacecraft. Note also the weak, secondary spikes both in the magnetosheath and beyond the shock in interplanetary space.

Figure 2: Schematic view of phenomena at the magnetopause and beyond. Underlying all these effects are the hydromagnetic oscillations, probably surface waves, on the magnetopause. The bow shock spikes lie just behind the shock where they are accelerated and confined. The weaker spikes in the magnetosheath (T) and in interplanetary space (I) are due to electrons escaping from the acceleration-confinement region.

Figure 3: Counter arrangement used to make some of the measurements reported here. The open counter has a very thin window and counts 22 KeV electrons with about 90% efficiency.

Figure 4: Distribution of bow shock spikes in the X_{SE}-Y_{SE} plane. They are seen to occur on nearly all satellite orbits between the dusk and dawn meridians.

Figure 5: Examples of bow shock spikes showing that their intensity and temporal character does not vary greatly with spatial position between dusk and dawn.

Figure 6: Location of bow shock spikes and the related upstream events from the Explorer-35 spacecraft. The upstream events occur predominantly on the dawn side of the sun-earth line. This is due to their being guided by the interplanetary field from behind the bow shock where they are produced.

Figure 7: An example of bow shock spikes behind the dusk meridian is shown in part a. Part b shows spikes detected behind the dawn meridian.

Figure 8: An example of an upstream electron event at 60 R_e geocentric distance. The angle φ is the solar ecliptic longitude.

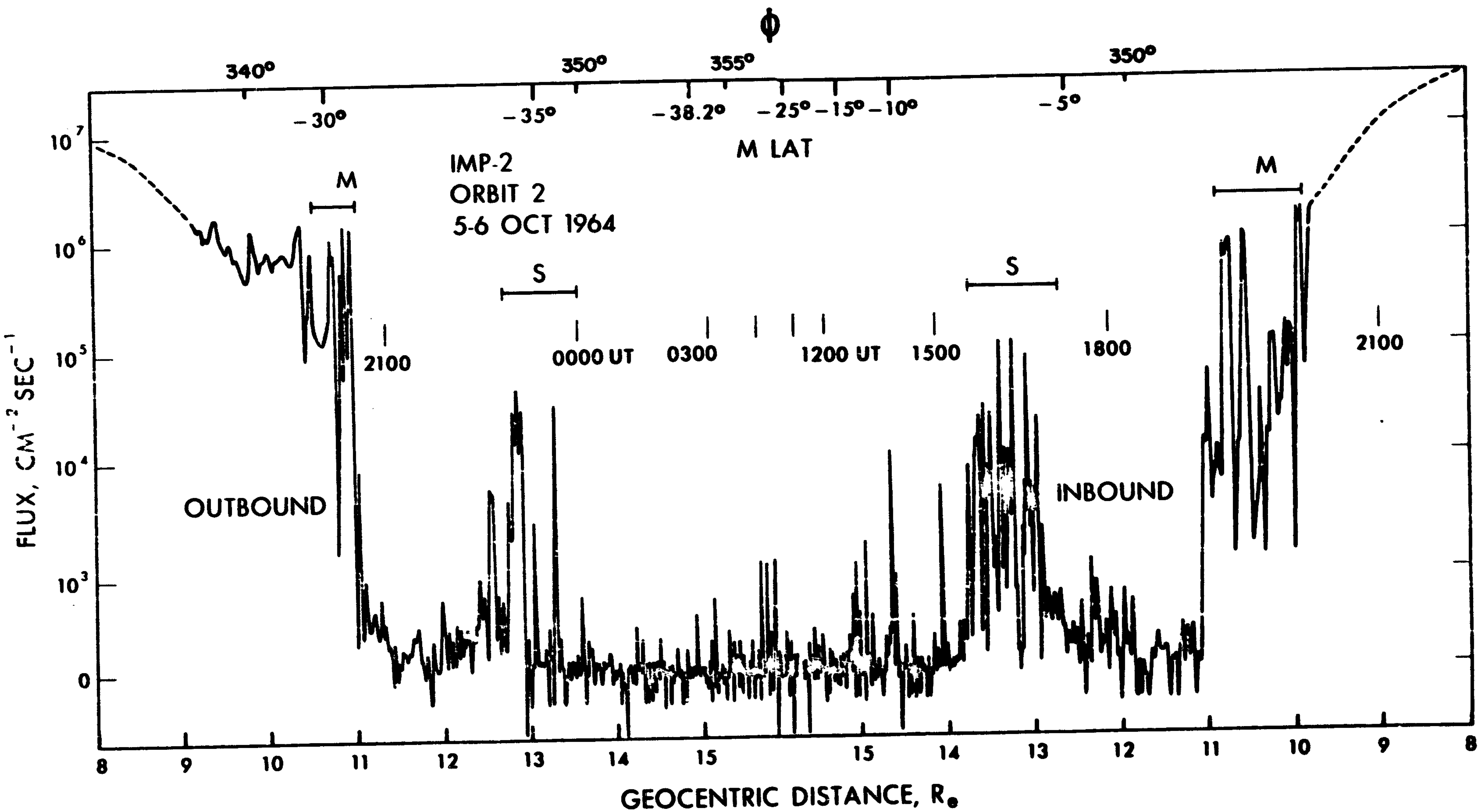
Figure 9: Same as 8.

Figure 10: Same as 8.

Figure 11: Bow shock spikes and simultaneous plasma data from the MIT experiment on IMP-2. The change in character of the plasma from interplanetary to magnetosheath shows that the bow shock spikes lie behind the shock. The duration of these spikes is about two minutes.

Figure 12: This bow shock spike occurred at a time when it is believed the bow shock was not moving rapidly. The duration of the spike is only about 40 seconds.

Figure 13: These bow shock spikes show a tendency to occur in clusters about a half hour apart. The width of individual spikes is a few minutes.



Φ
340°
350°
355°
350°
−30°
−35°
−38.2°
−25° −15° −10°
−5°
M LAT
IMP-2
ORBIT 2
5-6 OCT 1964
M
S
S
M
2100
0000 UT
0300
1200 UT
1500
1800
2100
OUTBOUND
INBOUND
FLUX, CM⁻² SEC⁻¹
10⁷
10⁶
10⁵
10⁴
10³
0
8
9
10
11
12
13
14
15
15
14
13
12
11
10
9
8
GEOCENTRIC DISTANCE, Rₑ

Figure 1

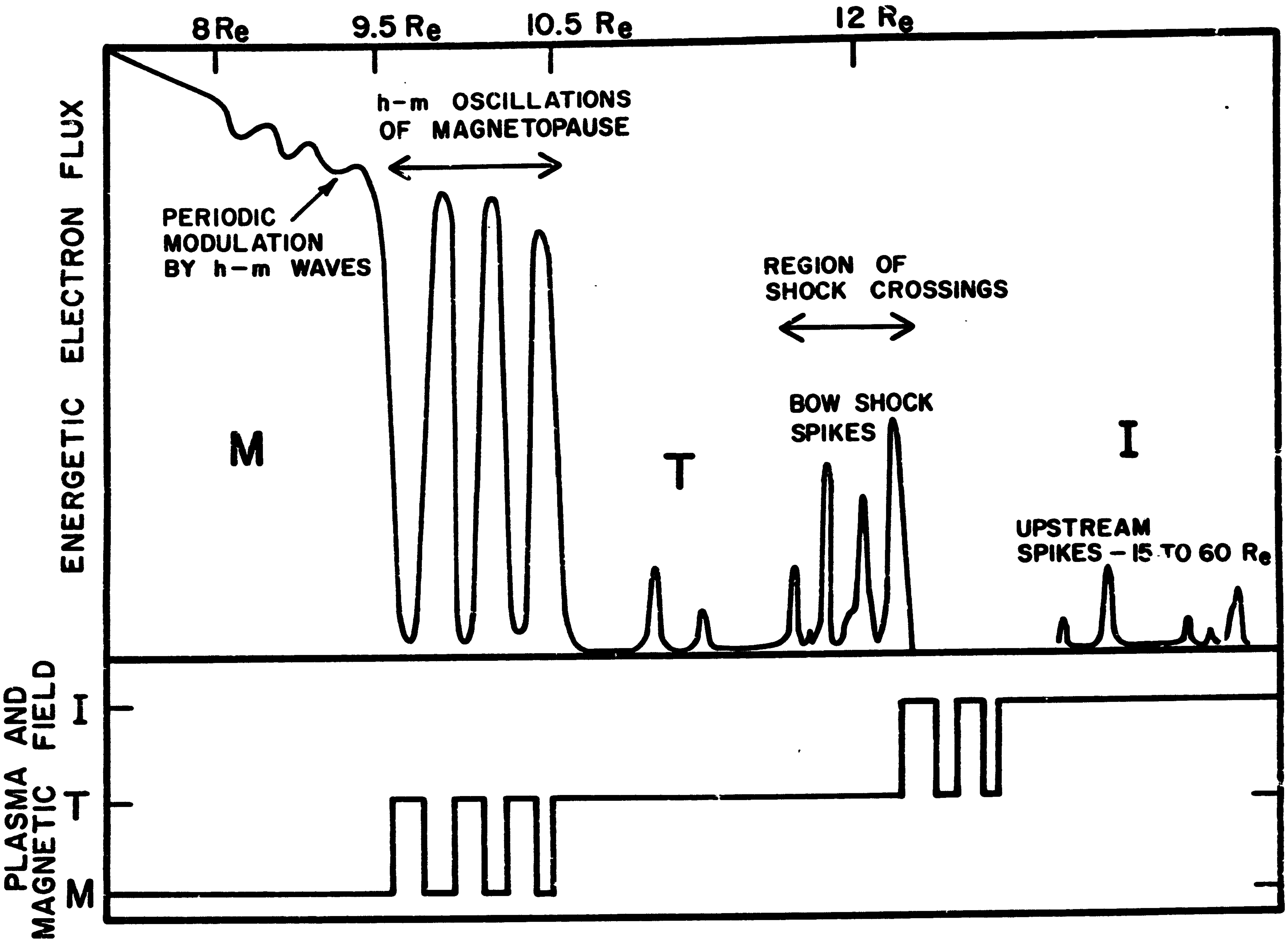

8 Re
9.5 Re
10.5 Re
12 Re
ENERGETIC ELECTRON FLUX
h-m OSCILLATIONS OF MAGNETOPAUSE
PERIODIC MODULATION BY h-m WAVES
REGION OF SHOCK CROSSINGS
BOW SHOCK SPIKES
UPSTREAM SPIKES – 15 TO 60 Re
M
T
I
PLASMA AND MAGNETIC FIELD

Figure 2

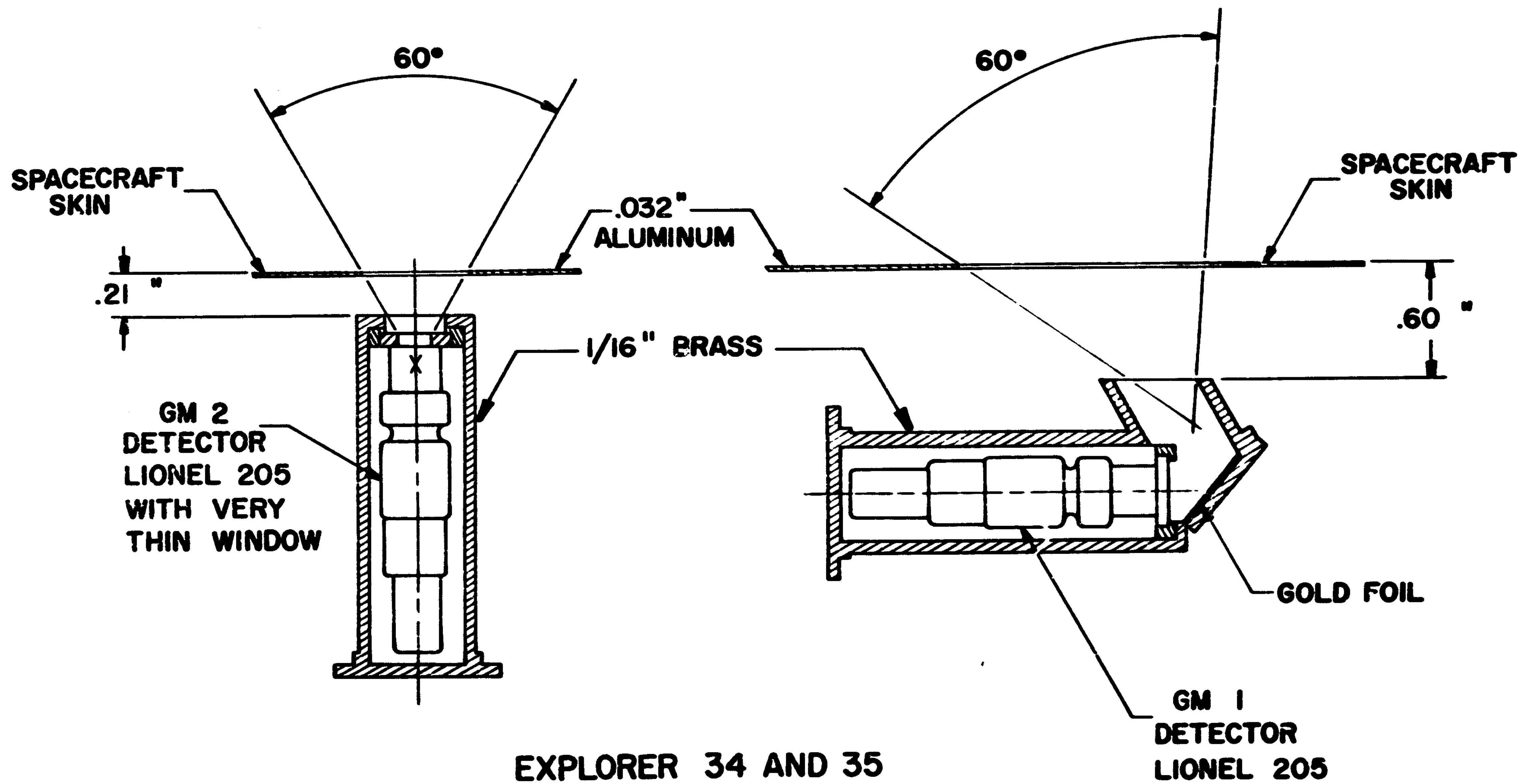

60°
60°
SPACECRAFT SKIN
.032" ALUMINUM
SPACECRAFT SKIN
.21"
.60"
1/16" BRASS
GM 2 DETECTOR LIONEL 205 WITH VERY THIN WINDOW
GOLD FOIL
GM 1 DETECTOR LIONEL 205
EXPLORER 34 AND 35

Figure 3

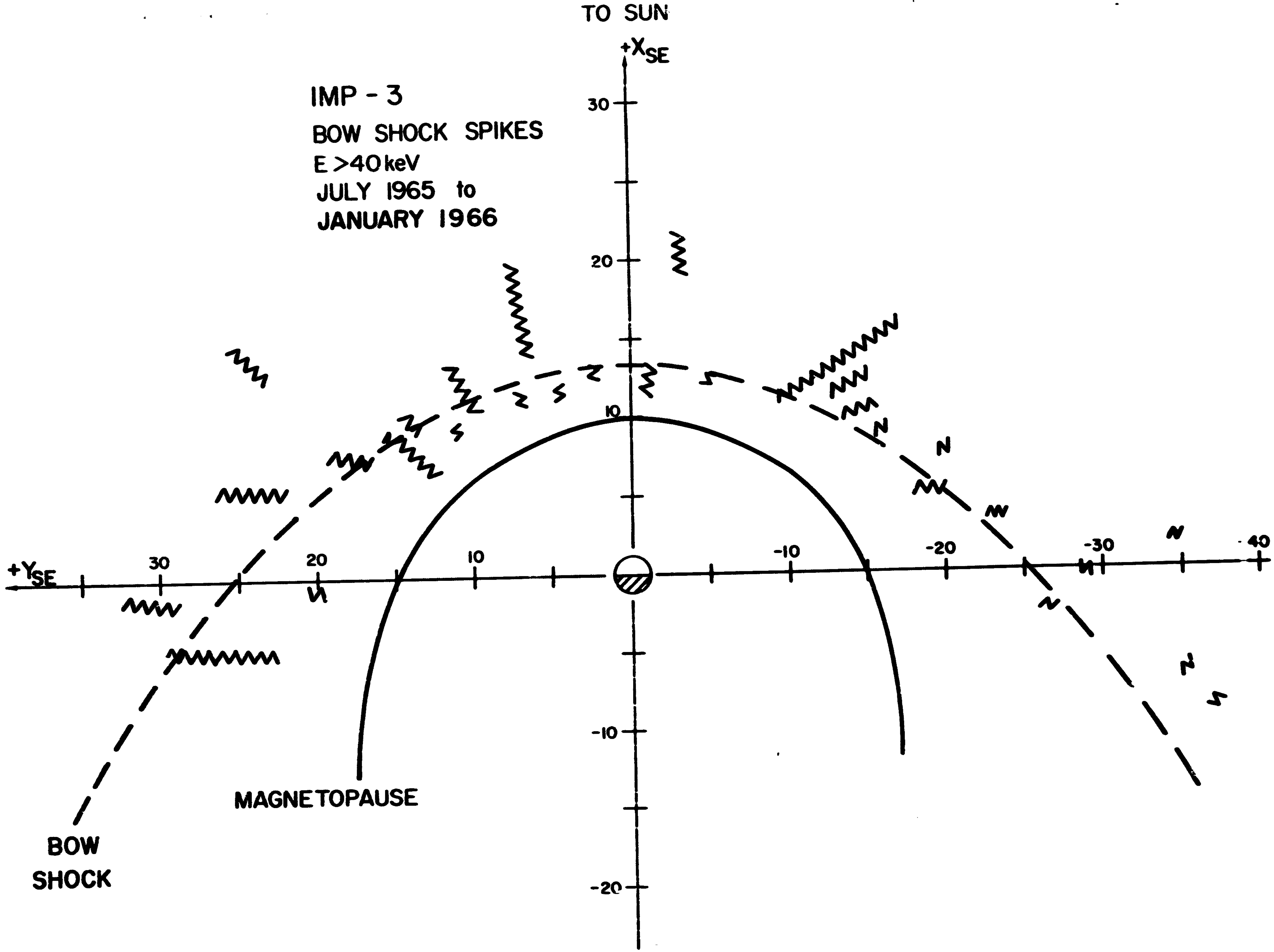
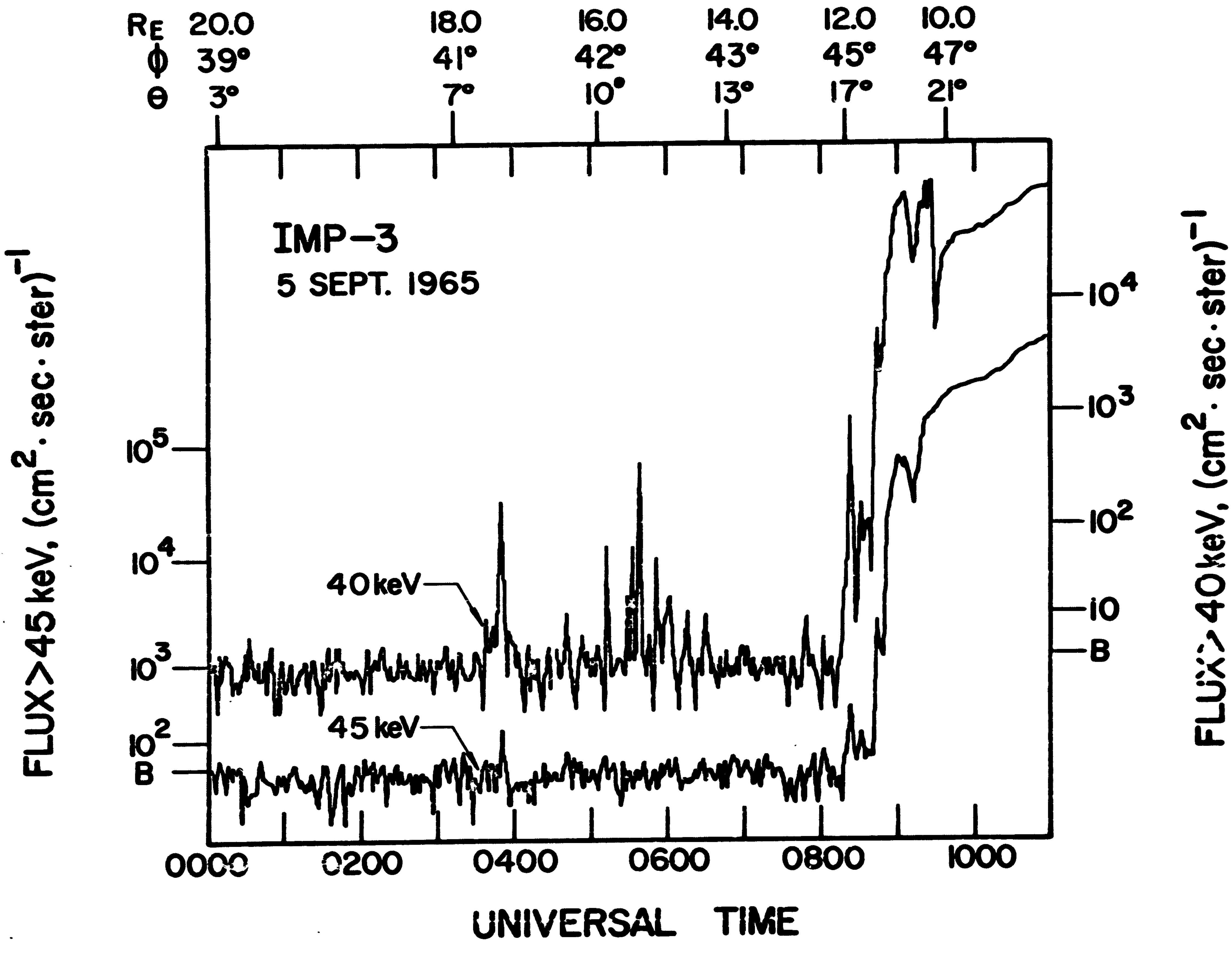
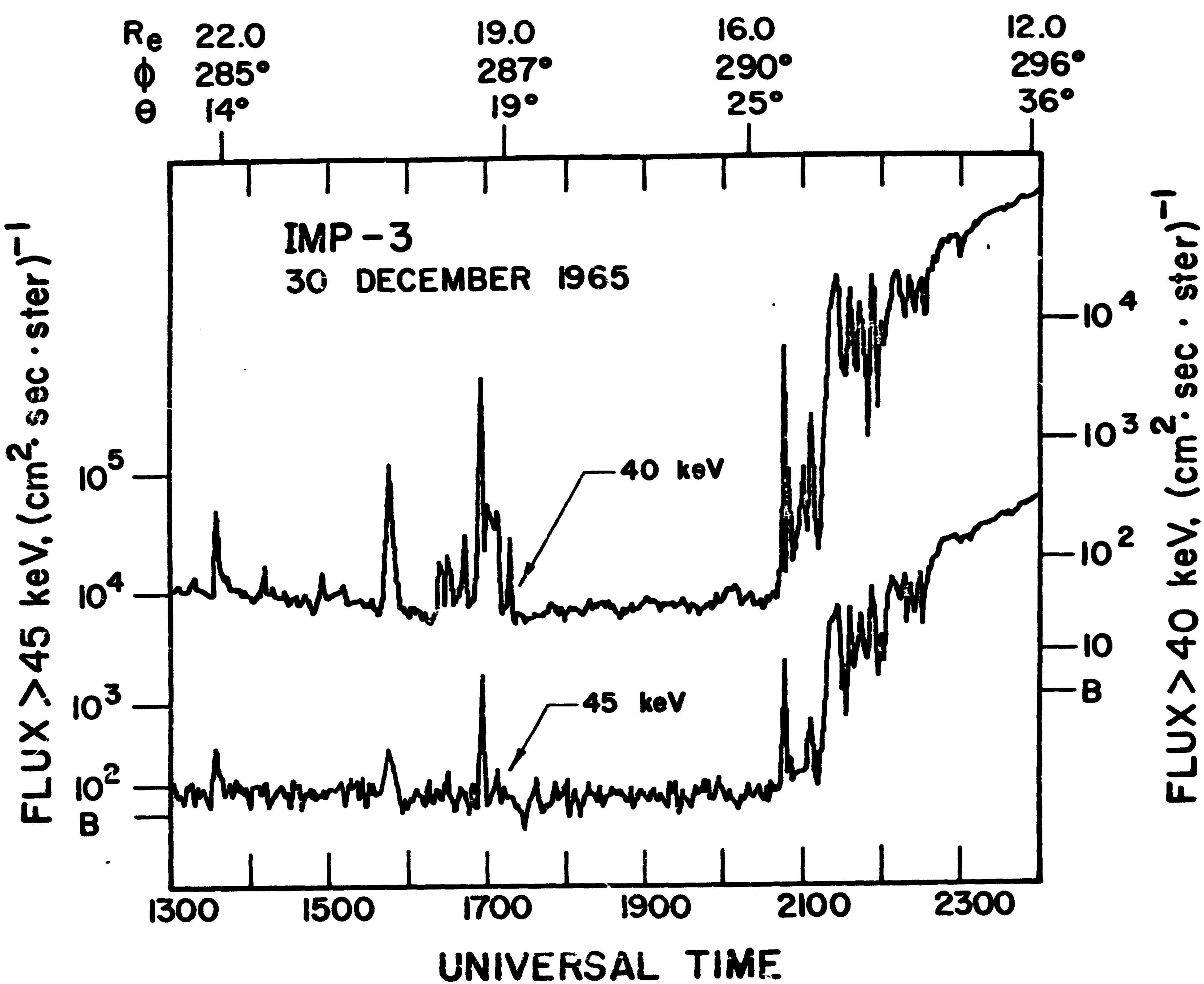

TO SUN
$+X_{SE}$
IMP - 3
BOW SHOCK SPIKES
E >40 keV
JULY 1965 to
JANUARY 1966
30
20
10
-10
-20
$+Y_{SE}$
30
20
10
-10
-20
-30
-40
MAGNETOPAUSE
BOW
SHOCK

Figure 4

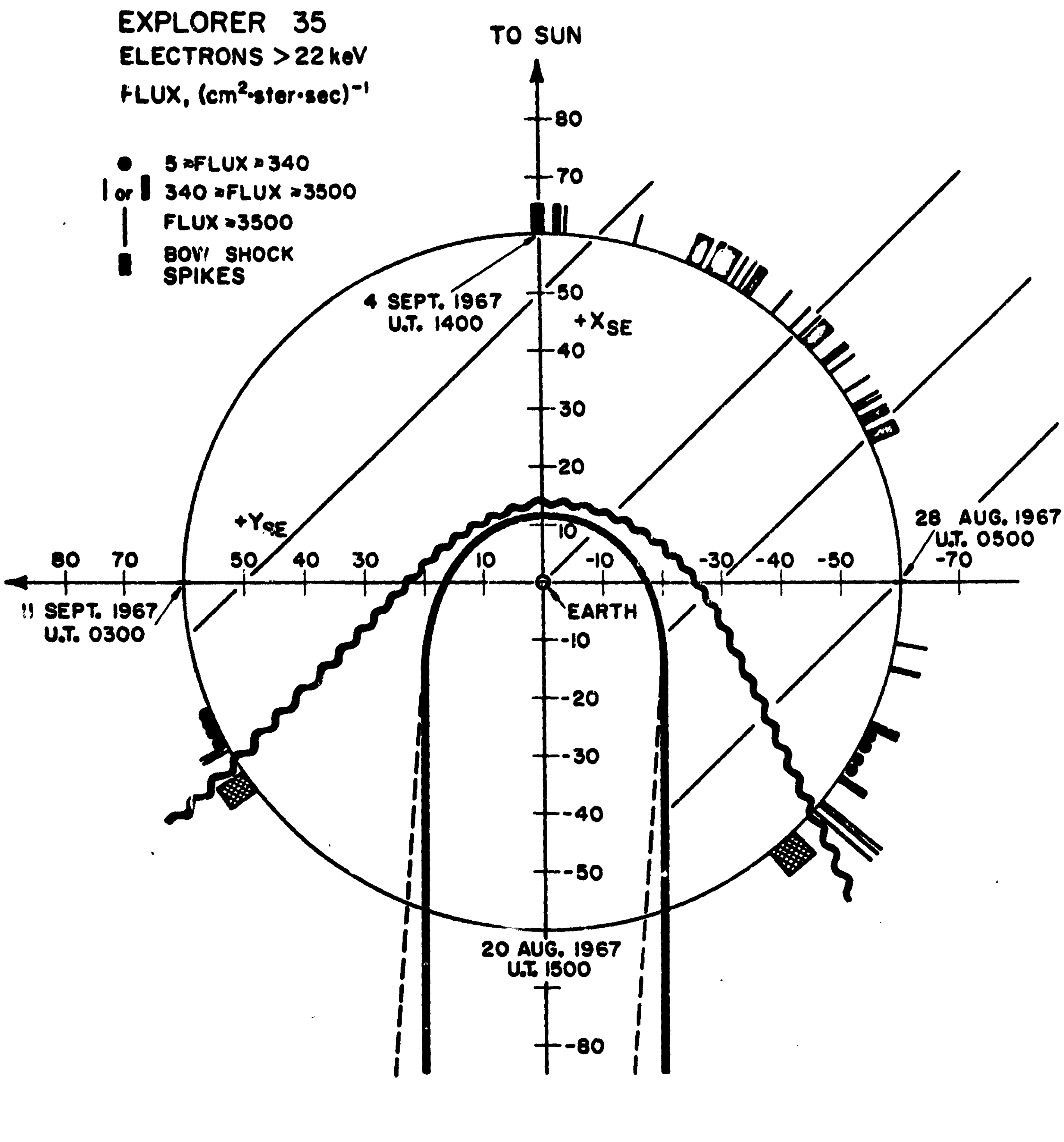


IMP-3
5 SEPT. 1965
R_E 20.0 18.0 16.0 14.0 12.0 10.0
ϕ 39° 41° 42° 43° 45° 47°
θ 3° 7° 10° 13° 17° 21°
40 keV
45 keV
10^5
10^4
10^3
10^2
B
10
FLUX>45 keV, $(cm^2 \cdot sec \cdot ster)^{-1}$
FLUX>40 keV, $(cm^2 \cdot sec \cdot ster)^{-1}$
0000
0200
0400
0600
0800
1000
UNIVERSAL TIME



Re 22.0 19.0 16.0 12.0
Φ 285° 287° 290° 296°
Θ 14° 19° 25° 36°
IMP-3
30 DECEMBER 1965
40 keV
45 keV
FLUX > 45 keV, (cm^2· sec · ster)$^{-1}$
10^5
10^4
10^3
10^2
B
FLUX > 40 keV, (cm^2· sec · ster)$^{-1}$
10^4
10^3
10^2
10
B
1300
1500
1700
1900
2100
2300
UNIVERSAL TIME

Figure 5b



EXPLORER 35
ELECTRONS > 22 keV
FLUX, (cm²·ster·sec)⁻¹
5 ≥ FLUX ≥ 340
or 340 ≥ FLUX ≥ 3500
FLUX ≥ 3500
BOW SHOCK SPIKES
TO SUN
80
70
50
40
30
20
10
-10
-20
-30
-40
-50
-80
+X_SE
+Y_SE
4 SEPT. 1967 U.T. 1400
28 AUG. 1967 U.T. 0500
11 SEPT. 1967 U.T. 0300
20 AUG. 1967 U.T. 1500
EARTH
-30
-40
-50
-70

Figure 6a

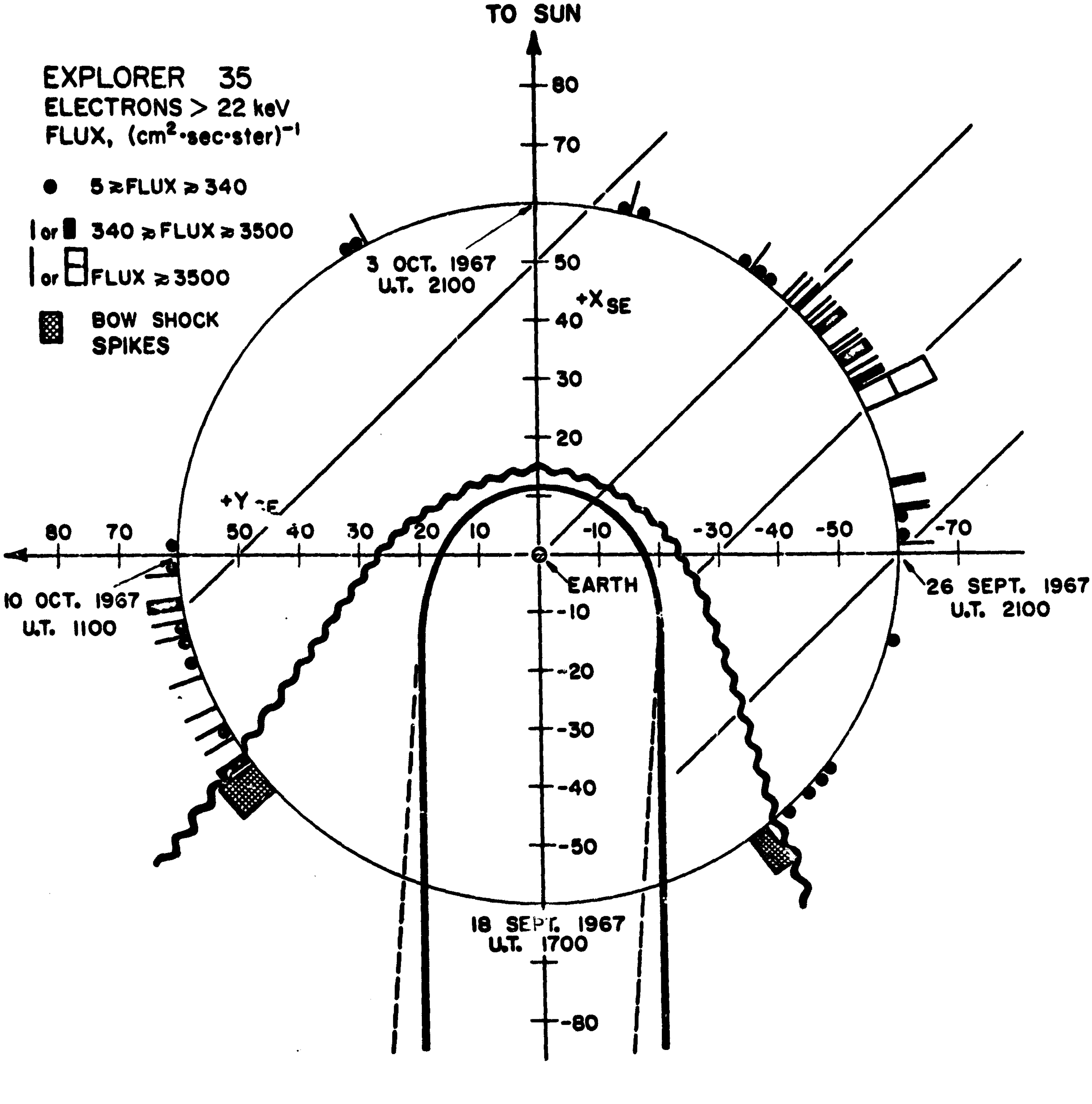
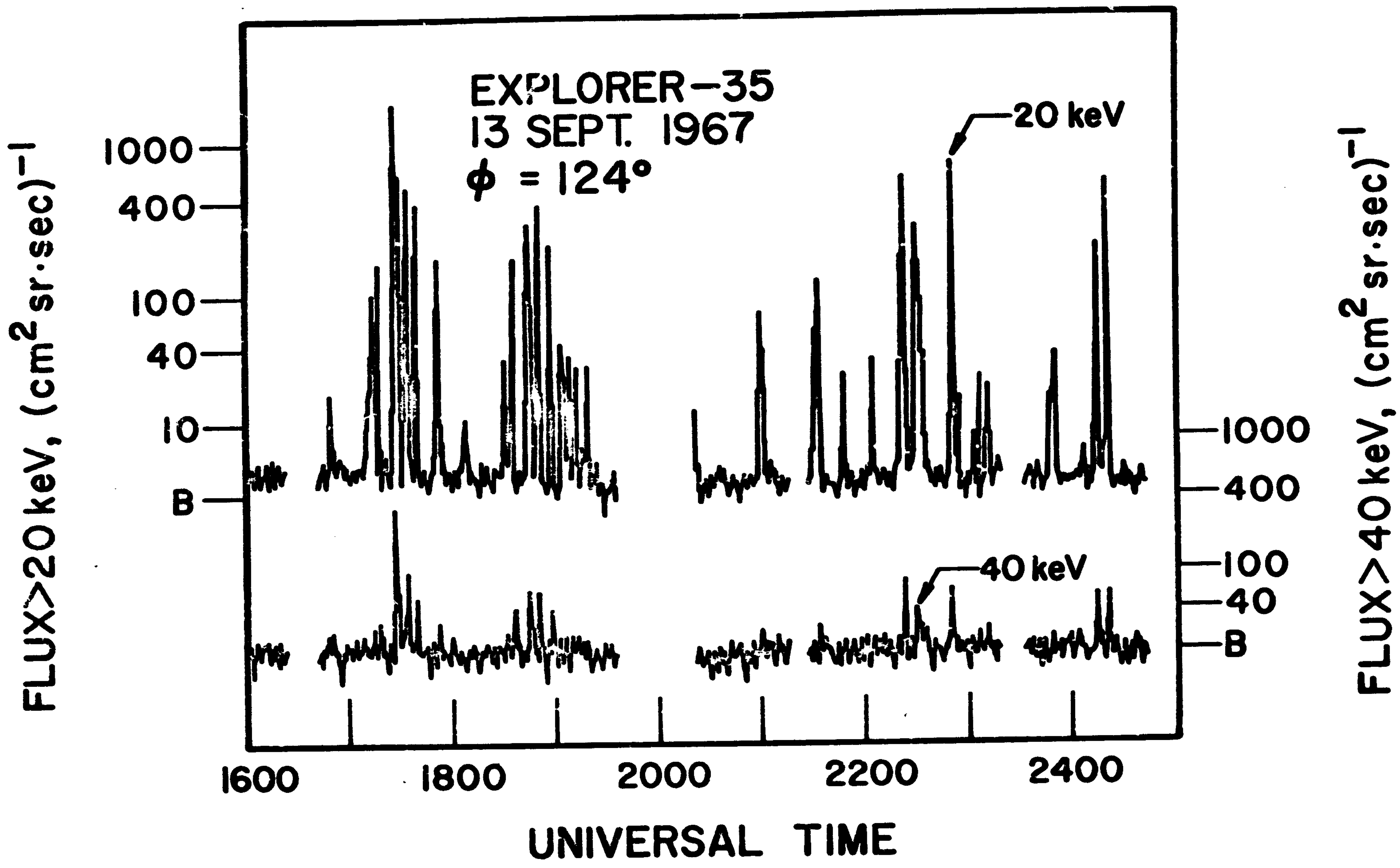
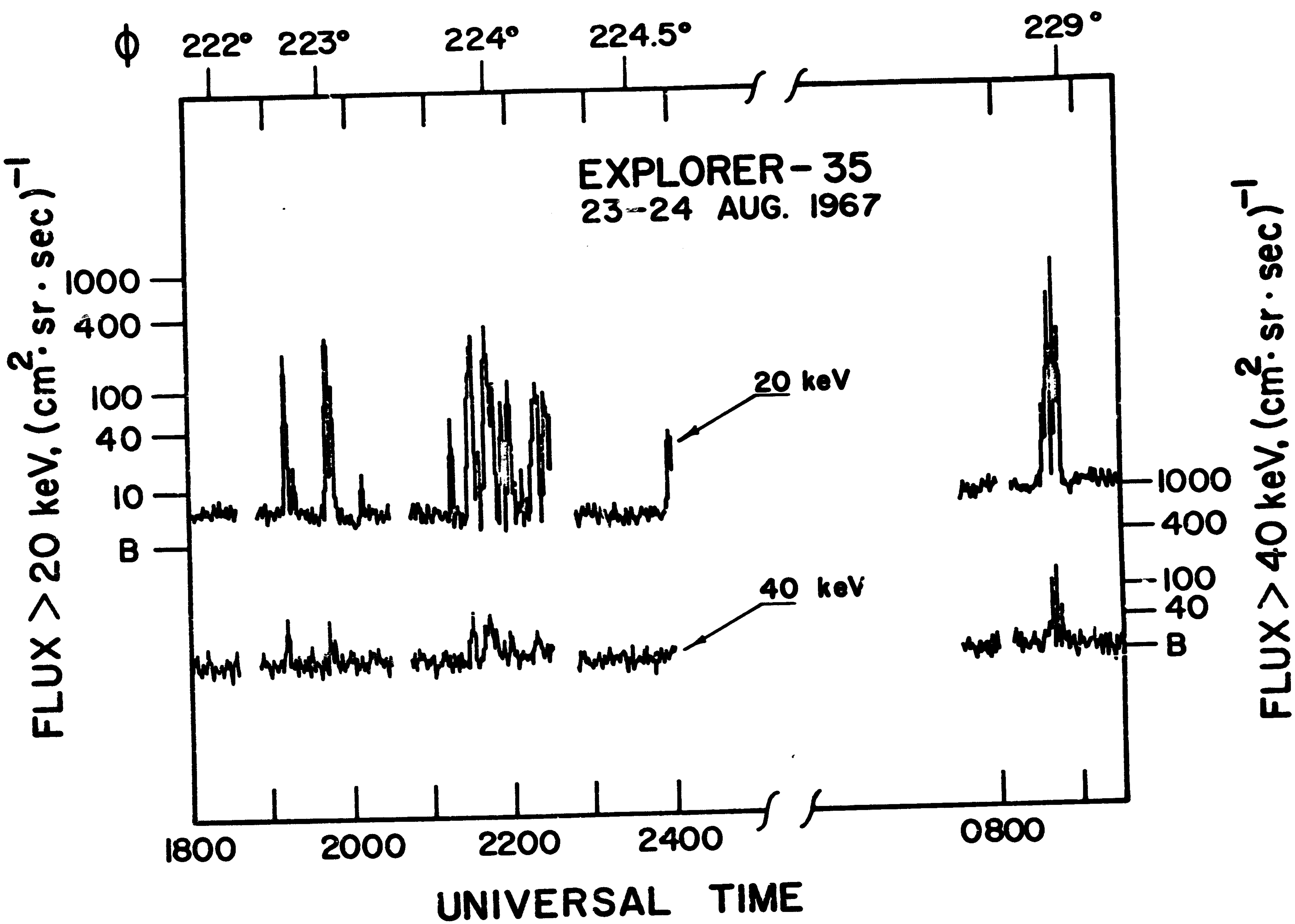

TO SUN
EXPLORER 35
ELECTRONS > 22 keV
FLUX, (cm²·sec·ster)⁻¹
5 ≥ FLUX ≥ 340
or 340 ≥ FLUX ≥ 3500
or FLUX ≥ 3500
BOW SHOCK
SPIKES
80
70
50
40
30
20
-10
-20
-30
-40
-50
-80
+X SE
+Y SE
3 OCT. 1967
U.T. 2100
10 OCT. 1967
U.T. 1100
26 SEPT. 1967
U.T. 2100
18 SEPT. 1967
U.T. 1700
EARTH
10
-70

Figure 6b



EXPLORER-35
13 SEPT. 1967
ϕ = 124°
20 keV
40 keV
FLUX>20 keV, (cm² sr·sec)⁻¹
1000
400
100
40
10
B
FLUX>40 keV, (cm² sr·sec)⁻¹
1000
400
100
40
B
1600
1800
2000
2200
2400
UNIVERSAL TIME

Figure 7a



φ
222°
223°
224°
224.5°
229°
EXPLORER - 35
23-24 AUG. 1967
FLUX > 20 keV, (cm^2· sr · sec)$^{-1}$
1000
400
100
40
10
B
20 keV
40 keV
FLUX > 40 keV, (cm^2· sr · sec)$^{-1}$
1000
400
100
40
B
1800
2000
2200
2400
0800
UNIVERSAL TIME

Figure 7b

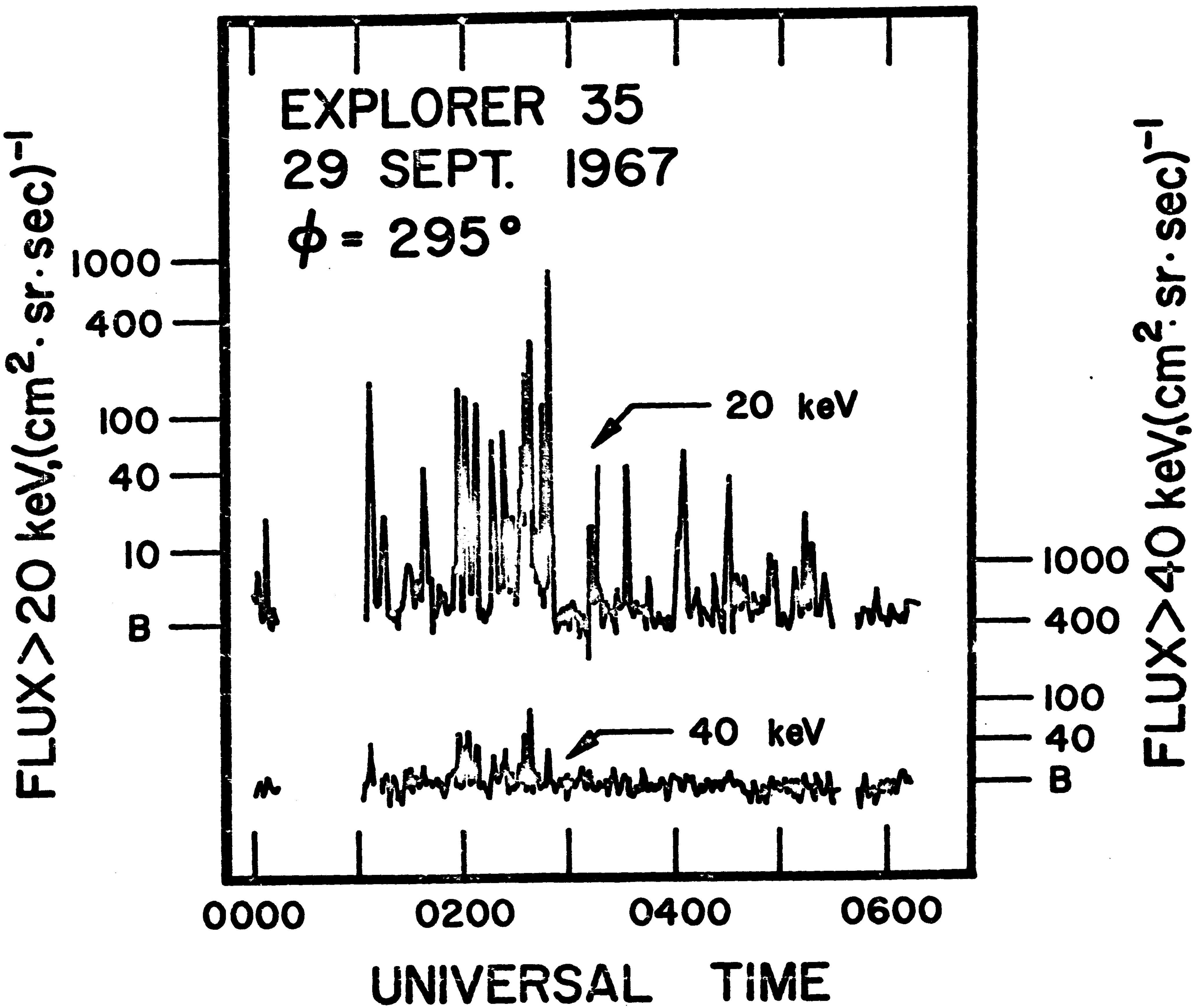
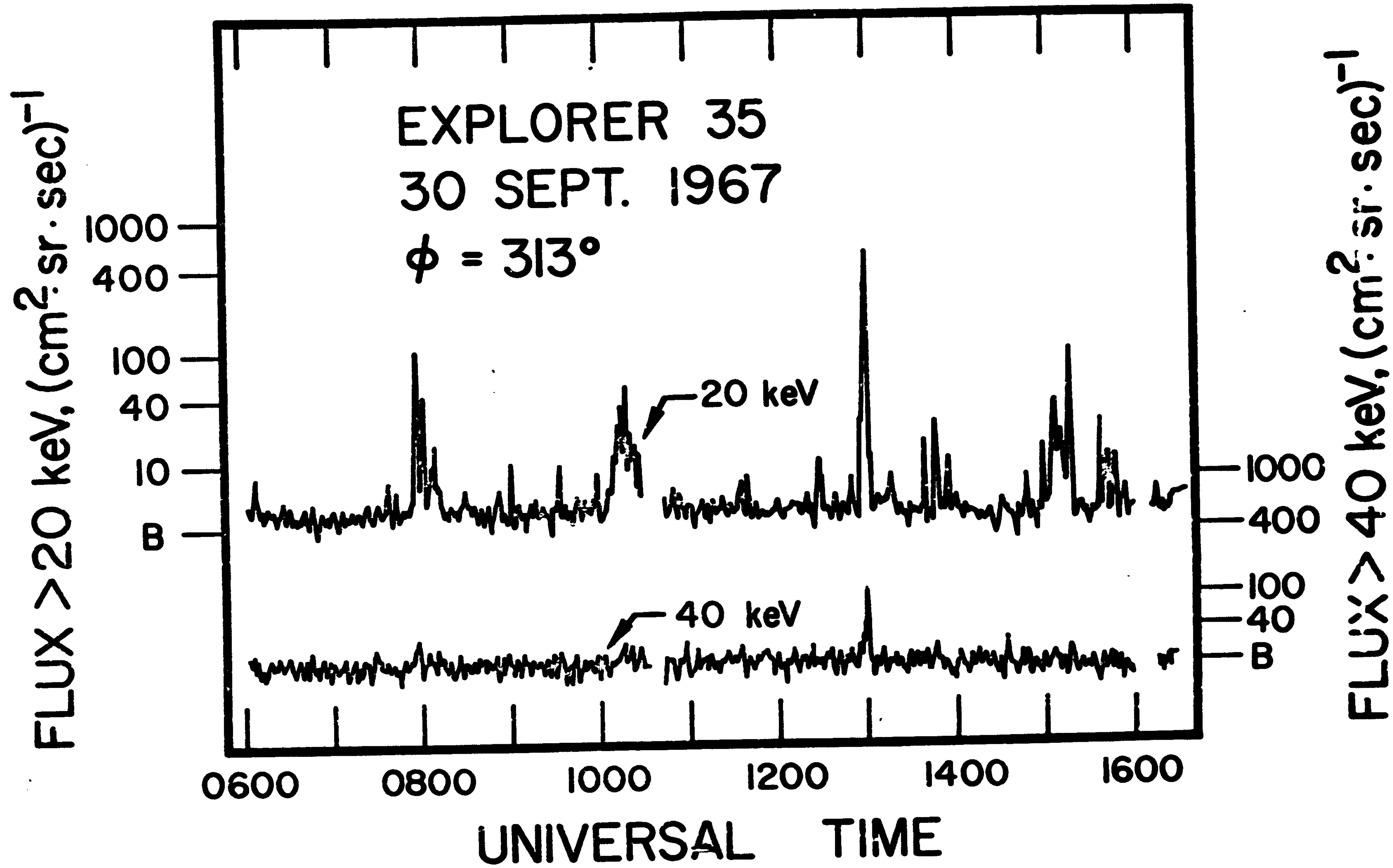
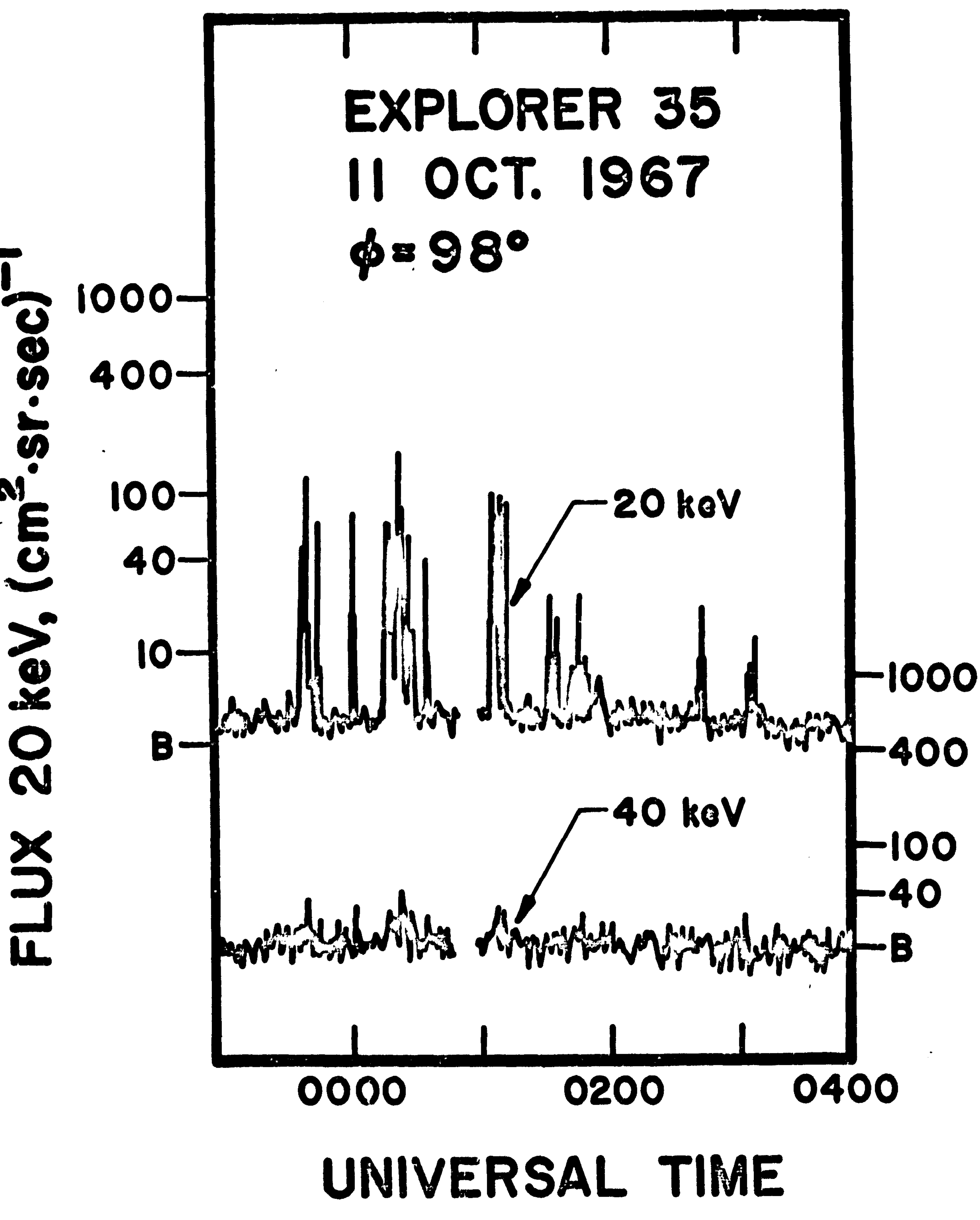

EXPLORER 35
29 SEPT. 1967
φ = 295°
20 keV
40 keV
FLUX>20 keV,(cm2. sr. sec)-1
1000
400
100
40
10
B
FLUX>40 keV,(cm2. sr. sec)-1
1000
400
100
40
B
0000
0200
0400
0600
UNIVERSAL TIME

Figure 8



EXPLORER 35
30 SEPT. 1967
φ = 313°
20 keV
40 keV
FLUX >20 keV, (cm²· sr · sec)⁻¹
1000
400
100
40
10
B
FLUX > 40 keV, (cm²· sr · sec)⁻¹
1000
400
100
40
B
0600
0800
1000
1200
1400
1600
UNIVERSAL TIME

Figure 9



EXPLORER 35
11 OCT. 1967
φ = 98°
20 keV
40 keV
1000
400
100
40
10
B
1000
400
100
40
B
0000
0200
0400
UNIVERSAL TIME
FLUX 20 keV, (cm²·sr·sec)⁻¹
FLUX 40 keV, (cm²·sr·sec)⁻¹

Figure 10

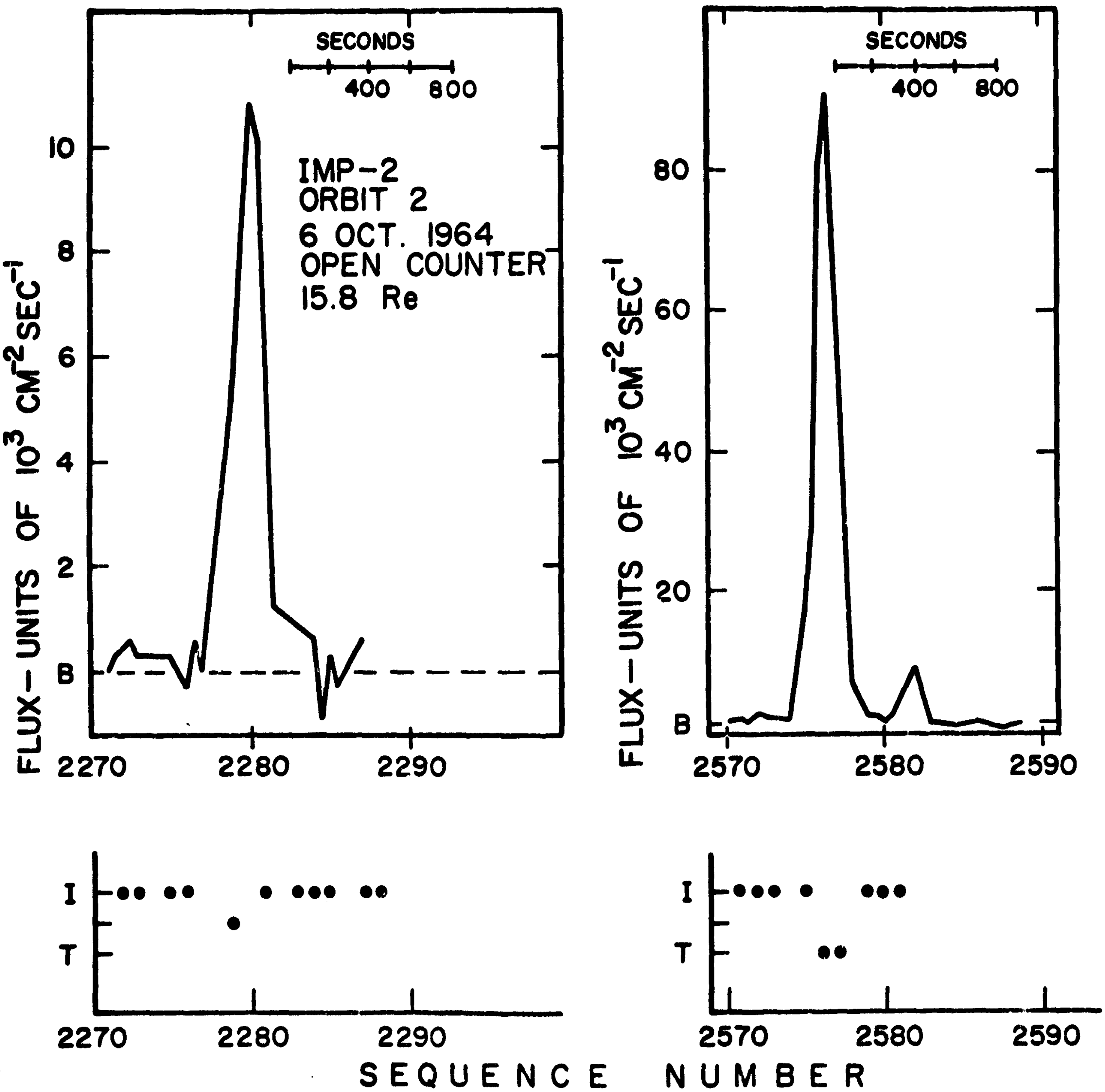

SECONDS
400
800
IMP-2
ORBIT 2
6 OCT. 1964
OPEN COUNTER
15.8 Re
FLUX—UNITS OF 10^3 CM^{-2}SEC^{-1}
10
8
6
4
2
B
2270
2280
2290
2570
2580
2590
80
60
40
20
I
T
SEQUENCE NUMBER

Figure 11

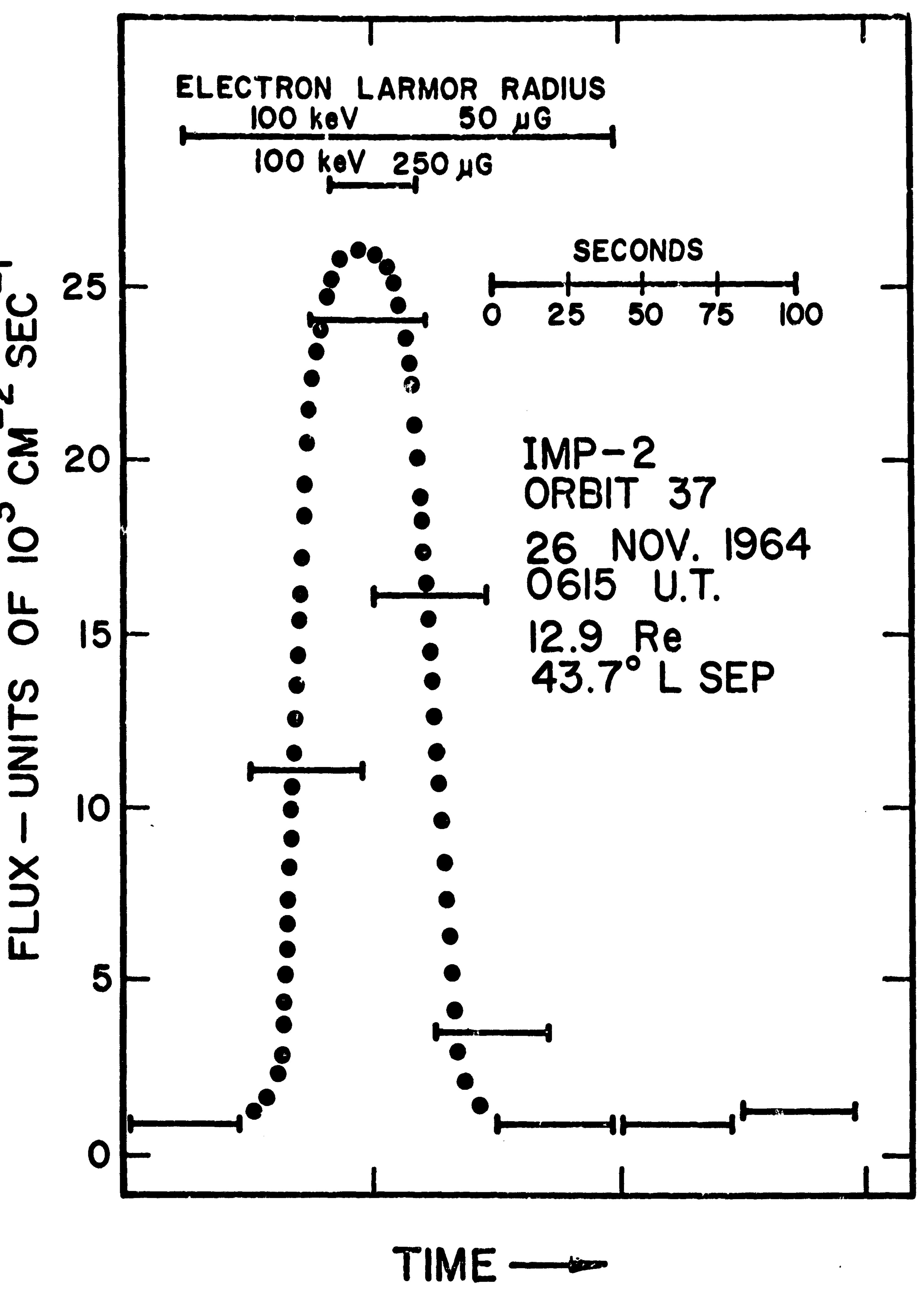

ELECTRON LARMOR RADIUS
100 keV 50 μG
100 keV 250 μG
SECONDS
0 25 50 75 100
IMP-2
ORBIT 37
26 NOV. 1964
0615 U.T.
12.9 Re
43.7° L SEP
FLUX – UNITS OF 10³ CM⁻² SEC⁻¹
0
5
10
15
20
25
TIME

Figure 12

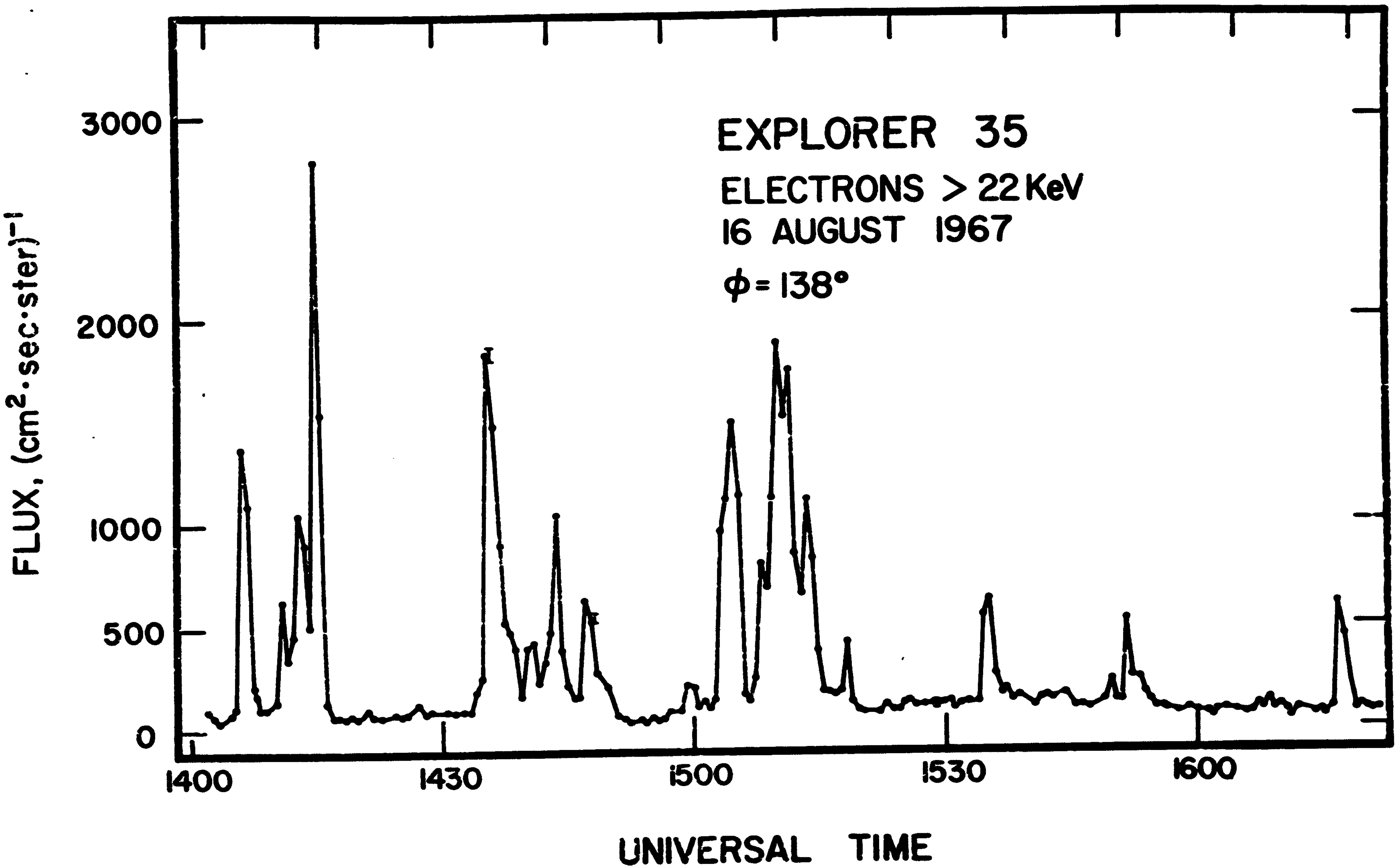

EXPLORER 35
ELECTRONS > 22 KeV
16 AUGUST 1967
ϕ = 138°
3000
2000
1000
500
0
FLUX, (cm²·sec·ster)⁻¹
1400
1430
1500
1530
1600
UNIVERSAL TIME

Figure 13a